

**USARIEM TECHNICAL REPORT T-02/15**

**PROGRESS IN DEVELOPMENT OF A MINIATURE ENVIRONMENTAL HEAT  
STRESS MONITOR (HSM)**

**DISTRIBUTION STATEMENT A**  
Approved for Public Release  
Distribution Unlimited

William T. Matthew  
Richard R. Gonzalez  
Julio A. Gonzalez

Biophysics and Biomedical Modeling Division

January 2002

U.S. Army Research Institute of Environmental Medicine  
Natick, MA 01760-5007

**20020329 092**

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE JAN 2002		3. REPORT TYPE AND DATES COVERED Technical Report	
4. TITLE AND SUBTITLE PROGRESS IN DEVELOPMENT OF A MINIATURE ENVIRONMENTAL HEAT STRESS MONITOR (HSM)				5. FUNDING NUMBERS	
6. AUTHOR(S) WILLIAM T. MATTHEW, RICHARD R. GONZALEZ, AND JULIO A. GONZALEZ					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Institute of Environmental Medicine Kansas Street Natick, MA 01760-50076				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, MD 21702-5007				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  The environmental heat stress monitor (HSM) is a pocket-sized electronic device that uses microprocessor technology to integrate the USARIEM heat strain prediction model software with a comprehensive suite of environmental sensors. It can provide real-time tailored guidance to reduce heat injury risk across the spectrum of heat stress environments including chemical protective clothing encapsulation. This report describes current status of the HSM as it has evolved through a series Army technology base efforts to support potential Army applications and related efforts undertaken through a cooperative research and development agreement (CRDA) to develop a hand-held heat stress monitor suitable for application in Australian industry.					
14. SUBJECT TERMS heat stress monitor, environmental sensor				15. NUMBER OF PAGES 23	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT U	18. SECURITY CLASSIFICATION OF THIS PAGE U	19. SECURITY CLASSIFICATION OF ABSTRACT U	20. LIMITATION OF ABSTRACT U		

## TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
List of Figures.....	v
Acknowledgments .....	vi
Executive Summary .....	1
Introduction .....	2
Overview .....	2
Dual use Strategy .....	2
Background .....	3
First Generation HSM .....	3
Second Generation HSM .....	3
Objectives.....	3
Methods .....	3
Contract Efforts.....	3
Calibration and Test .....	4
Wind Tunnel .....	4
Outdoor Tests .....	4
Army User Tests .....	4
Cooperative Research and Development Agreement .....	4
Results .....	5
HSM Prototypes .....	5
Physical Characteristics .....	5
Key Operating Features .....	6
Interchangeable Sensor Module.....	7
Sensor Accuracy .....	7
Wind Speed Sensor .....	7
HSM Sensor Performance.....	8
Outdoor Testing .....	8
Military User Comments .....	11
4 <sup>th</sup> Ranger Training Battalion .....	12
5 <sup>th</sup> Ranger Training Battalion .....	12
6 <sup>th</sup> Ranger Training Battalion .....	12
75 <sup>th</sup> Ranger Regiment .....	12
CRDA-Related Activities.....	12

Cooperative Efforts .....	12
Meeting at USAMMDA .....	13
HSM Patent Activities .....	14
Discussion .....	14
HSM Technical Maturity .....	14
HSM Applications .....	14
Technology Transfer.....	15
Conclusions.....	16
HSM Technology Status.....	16
Sensors.....	16
Wind Speed Calibration .....	16
Army Users .....	16
Technology Transfer/Dual Use .....	16
Recommendations .....	16
References.....	17

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Miniature Environmental Heat Stress Monitor (HSM)	2
2	Heat Stress Monitor with sensors deployed	5
3	Rear cover of Heat Stress Monitor open for sensor storage	6
4	Field replaceable sensor module	6
5	Typical wind speed sensor responses at 21 and 40 °C	8
6	Heat Stress Monitor wind speed measurements outdoors	9
7	Heat Stress Monitor air temperature measurements outdoors	10
8	Heat Stress Monitor relative humidity measurements outdoors	10
9	Solar radiation influence on HSM relative humidity readings	11

## **ACKNOWLEDGMENTS**

The authors would like to thank the Commander, 4<sup>th</sup> Ranger Training Brigade and medical staff of the 75<sup>th</sup> Ranger Regiment for their support in the preliminary user level evaluations of the prototype environmental Heat Stress Monitor.

## EXECUTIVE SUMMARY

The environmental heat stress monitor (HSM) is a pocket-sized electronic device that uses microprocessor technology to integrate the USARIEM heat strain prediction model software with a comprehensive suite of environmental sensors. It can provide real-time tailored guidance to reduce heat injury risk across the spectrum of heat stress environments including chemical protective clothing encapsulation. This report describes current status of the HSM as it has evolved through a series of Army technology base efforts to support potential Army applications and related efforts undertaken through a cooperative research and development agreement (CRDA) to develop a hand-held heat stress monitor suitable for application in Australian industry.

Most of the incrementally phased developmental work on the HSM, including baseline packaging, software, firmware, and hardware design, was performed under a series of USARIEM-specified contract tasks by Southwest Research Institute (SwRI), San Antonio, Texas. Consistent with provisions of the CRDA with Occ-Consult, Perth, Australia, development information was shared, and in several instances we leveraged technical advances achieved by our CRDA partner's own contract efforts with SwRI.

The maturity level of the integrated technologies embodied in the current HSM is high. User interfaces are logical and easy to use. The on board calibration and system diagnostic resources as well as the PC-based communications and display software systems are solid. The only development issues as yet unresolved are streamlining wind speed sensor calibration procedures and implementing a rational firmware solution to mitigate the apparent effects of high ambient solar radiation on air temperature and humidity measurement accuracy. Work is underway to characterize the relevant interactions and develop the necessary algorithms.

Despite encouraging responses from Army Ranger units that took an early look at the suitability of the HSM in training applications, this device has found no strong proponent within the Army to support final development and fielding. In limited production quantities, the current unit cost of about \$3,600 would be prohibitive for most potential Army users. A unit cost of \$1,500 to \$2,000, competitive with existing electronic WBGT meters, is possible but is not likely to be achieved until economies of scale can be exploited in a mass production manufacturing environment.

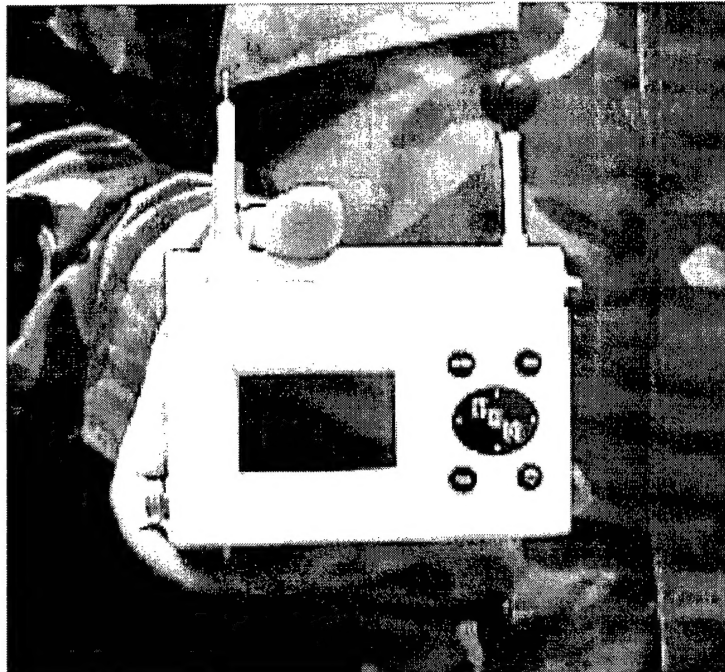
The effective transfer of HSM technology from the Army to the commercial sector is complicated by the as yet unresolved USARIEM patent submission and an existing SwRI patent. The current uncertainty in Army IP rights in HSM is likely to discourage interested manufacturers from getting involved, so a clear and timely resolution of that issue is the crucial first step in transferring this technology.

## INTRODUCTION

### OVERVIEW

The environmental heat stress monitor (HSM) is a pocket-sized electronic device that uses microprocessor technology to integrate the USARIEM heat strain prediction model (3,5) software with a comprehensive suite of environmental sensors. It can provide real-time tailored guidance to reduce heat injury risk across the spectrum of heat stress environments including chemical protective clothing encapsulation. Army technology base investments in the

**Figure 1. Miniature environmental Heat Stress Monitor (HSM).**



refinement of this device have resulted in a fairly mature product that has, thus far, found no strong proponent within the Army to support final development and fielding. Figure 1 depicts the current HSM.

### DUAL USE STRATEGY

This report describes current status of the HSM as it has evolved through a series Army technology base efforts to support potential Army applications and related efforts undertaken through a cooperative research and development agreement (CRDA) to develop a hand-held heat stress monitor suitable for application in Australian industry. Workers in industrial settings in Australia routinely perform hard physical labor in extraordinarily hot environments such as surface and deep mine operations. In summer months, this large, motivated

population is especially vulnerable to heat effects, and the prevention of heat injury is a significant occupational health concern. Although the principle focus of the CRDA is commercial operations, a successful development would have significant dual use relevance to military operational settings where sustained hard physical activity in hot environments and/or NBC clothing encapsulation is required.

## **BACKGROUND**

### **First Generation HSM**

Comments from Army reviewers of USARIEM's first generation HSM indicated that significant reductions in HSM size and weight would be essential for acceptance in field applications. Under a previous CRDA, user level applicability testing and sensor accuracy evaluations of the first generation HSM prototypes were completed in hot industrial environments in Australia (4). Those results suggested that any commercially viable HSM for industrial applications would require significant functional enhancements.

### **Second Generation HSM**

It was determined that substantial HSM size and weight reductions could be achieved even with a quantum improvement in features and capabilities. Among these, the addition of a barometric pressure sensor to the HSM's initial suite of on-board sensors (air temperature, humidity, wind speed and solar radiation) would enable the specialized heat stress management algorithms in use at Australian mine locations, and would also allow a modified USARIEM heat strain model to more accurately assess heat effects on soldiers operating in high altitude regions. The consolidation of these and other features within a single device was intended to expand the range of potential applications for both military and industrial users. For the Army, should it commit to HSM, a commercially available HSM running specialized Army firmware, would provide the option for rapid acquisition as a non-developmental item (NDI).

## **OBJECTIVES**

The primary objectives are to describe the developmental status of a second generation environmental heat stress monitor that could support both military and civilian applications, and to summarize CRDA-related activities that occurred during the effective period of that agreement.

## **METHODS**

### **CONTRACT EFFORTS**

With the exception of the general conceptual design for HSM and the source code for the USARIEM heat strain model, most baseline HSM software, hardware, and firmware design work was performed under a series of USARIEM-specified contract tasks by Southwest Research Institute (SwRI), San Antonio,

Texas. A contract through Synectics Corporation and the U.S. Air Force Rome Laboratories to SwRI provided preliminary design and fabrication of an initial HSM prototype that embodied the reduced size and weight attributes considered to be essential for military users (Contract No.F30602-95-D-0028 ) (1). Three additional USARIEM contract efforts provided system design documentation and incrementally enabled the full functionality of the HSM as it currently exists: "Software Requirements Specification and High Level Design Description" (DAAK60-97-P-5061), "Development of Data Logging Feature for Miniaturized Heat Stress Monitor" (DAAN02-98-P-8502 ), and "Development of Firmware and Calibration Features for Miniaturized Heat Stress Monitor"(DAAN02-98-P-8632).

## **CALIBRATION AND TEST**

### **Wind Tunnel**

Calibration of prototype HSMs was conducted in USARIEM environmental chamber facilities using a portable wind tunnel system (Model WT4401-D, OMEGA, Inc., Stanford, Connecticut). Sensor modules were detached from the HSM body and inserted into the throat of the tunnel. Extension cables connected the sensor module to the HSM body outside the wind tunnel, and the HSM's RS-232 port allowed transmission of sensor data to a PC-based data acquisition system (Model 182540E-01, National Instruments, Inc., Austin, Texas). Technical assistance with initial set-up and calibration procedures at USARIEM was provided by SwRI as a contract task deliverable.

### **Outdoor Tests**

Limited outdoor tests of HSM prototypes were conducted on USARIEM grounds using a Remote Automated Weather Station (RAWS) system (Model 555 data collection platform and UBS-2000 ® software, Vaisala/Handar, Inc., Sunnyvale, California). Data from two tripod mounted HSMs were obtained at 6 minute intervals using the automated data logging feature of the HSM. These data were subsequently downloaded for comparison with contemporary data file segments from the RAWS system.

### **Army User Tests**

On 4 April 2000, instructional briefing and 4 HSM prototypes were provided to Commander, 4<sup>th</sup> Ranger Training Brigade and medical staff from 75<sup>th</sup> Ranger Regiment at Fort Benning, Georgia, for user-level evaluations.

## **COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT**

A CRDA between USARIEM and Occ-Consult Ltd (Perth, Australia) "Production Development of a Hand Held Heat Stress Monitor for Application in Australian Industry" (Control No. 9804-M-C227, DAMD17-98-0062) established the framework for a coordinated and synergistic technology advancement process for HSM. SwRI also performed extensive HSM-related development and fabrication work for our CRDA partner and thus played a central role in the finalization of the design elements embodied in the current HSM.

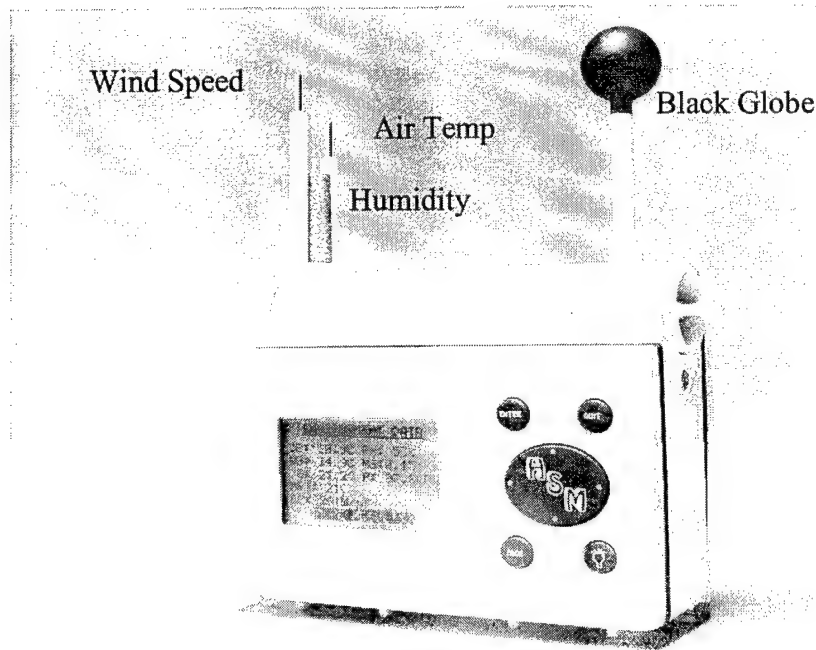
## RESULTS

### HSM PROTOTYPES

#### Physical Characteristics

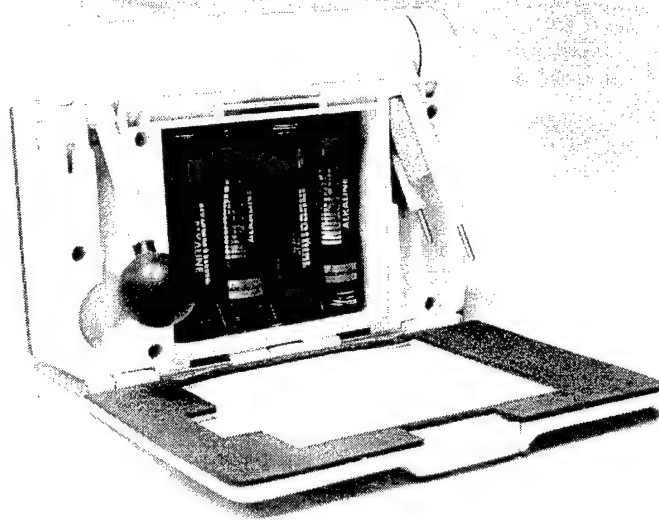
The injection molded plastic case is a clam shell design with an integrated hinge and latch closure mechanism. In its closed configuration, HSM dimensions are 4.75 x 3.5 x 1.5 inches (25 in<sup>3</sup>). Opening the rear cover allows the sensor module to be rotated into position for environmental measurements, and also provides access to the battery compartment. The system is powered by four standard AA alkaline batteries and has a total weight of 13 ounces. The field replaceable sensor module assembly consists of air temperature, humidity, wind speed, miniature black globe temperature, and barometric pressure sensors, and their analog/digital processing circuitry. The display is a text and graphics capable liquid crystal display (LCD) and has a back-light feature for use at night. User inputs and HSM function selection are accomplished through a miniature 5 button GPS-type keypad to the right of the LCD. An RS-232 port on the lower side of the case provides PC communications and a miniature threaded tripod mount on the bottom of the case allows secure attachment for unattended data logging applications. A total of 10 prototype HSMs were fabricated for USARIEM by SwRI. These prototypes used an improved prototype case design paid for by our CRDA partner. Figure 2 shows the HSM with environmental sensors in the deployed position.

**Figure 2. Heat Stress Monitor with sensors deployed.**

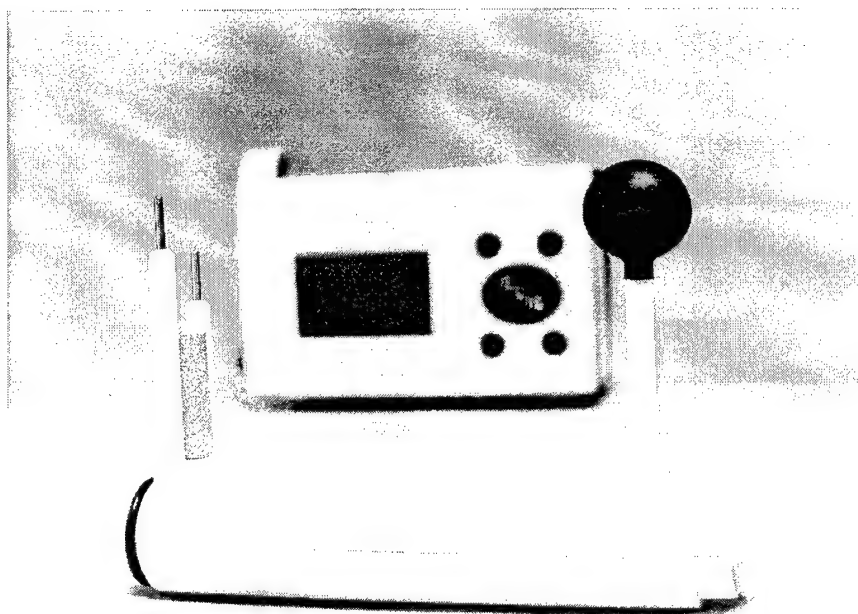


Mechanics of sensor module rotation into the case for storage or transport is shown in Figure 3.

**Figure 3. Rear cover of Heat Stress Monitor open for sensor storage.**



**Figure 4. Field replaceable sensor module.**



This integrated system and protective case design means there are no loose parts to fumble with or misplace during normal operations. An important element in the physical design of the miniature HSM is the ability to perform a field replacement of a damaged sensor module. Each sensor module contains an onboard chip with the necessary calibration constants. Figure three depicts the sensor module detached from the main body of the HSM.

### **Key Operating Features**

The system automatically displays current date/time and battery status on power-up. Entering the heat strain model, the user selects menu items for clothing type, work/task category (resting, very light, light, moderate, or heavy work), and acclimatization status (yes or no). After a 2 minute measurement period, the HSM displays hourly drinking water requirements, optimal work/rest cycle limits, and maximum safe work time for continuous work, as well as the 2-minute averaged environmental data used for these computations. A real-time sensor mode may also be selected to view real-time display of air temperature, wind speed, relative humidity, wet bulb temperature, black globe temperature, mean radiant temperature, WBGT index, and barometric pressure. Additional operating modes include: 1) *System setup* allows the user to set current date/time, and metric or English units for displayed parameters. 2) *Datalog setup* allows user select a start time, log time interval, and duration. 3) *Datalog review* allows user to view all logged data including predictive model outputs. 4) *Data log download* allows download of logged data through the RS-232 port to a PC for display with HSM software or import to a spreadsheet for analysis. 5) *Service mode* allows PC access through the RS-232 port for program updates, calibration, and system diagnostics.

## **INTERCHANGEABLE SENSOR MODULE**

### **Sensor Accuracy**

Stringent manufacturing tolerance specifications for sensor component parts are fundamental to achieving the overall HSM sensor accuracy requirements. Additionally, to enable the quick replacement of a bad or damaged HSM sensor module in the field, the calibration constants for each sensor must be electronically stored in the module itself. Constants for the barometric pressure, humidity, and temperature sensors are input at the time of fabrication. The wind speed sensor however requires a special process to achieve accuracy.

### **Wind Speed Sensor**

The wind speed sensor in the HSM is a heated bead anemometer system. In operation, ambient air temperature is continuously measured and an on-board power supply applies sufficient power to raise sensor temperature exactly 15 °C above ambient. Wind speed is a function of the power required to maintain that 15 °C overheat and the relationship has the following form:

$$V_a = a_0 \cdot \exp(a_1 \cdot P) + a_2 \quad (\text{Eq. 1})$$

Where,

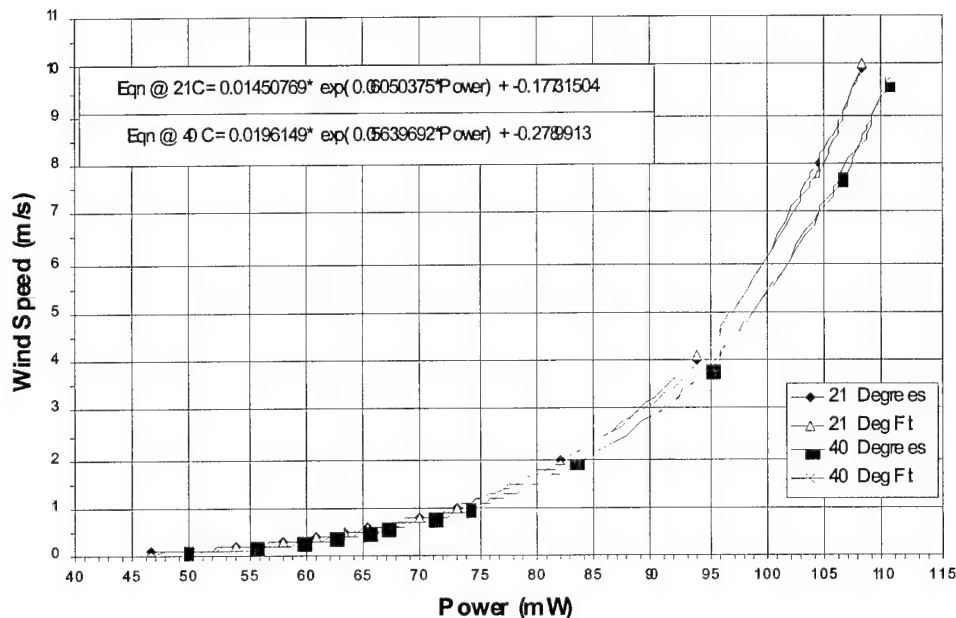
$V_a$  = wind speed in  $\text{m}\cdot\text{s}^{-1}$

$P$  = power in mW

$a_0$ ,  $a_1$ , and  $a_2$  are regression constants determined during calibration

The calibration procedure for the HSM's wind speed sensor is not simple. Because each anemometer has a slightly different response, it is necessary to determine  $a_0$ ,  $a_1$ , and  $a_2$  for every wind speed sensor. The current calibration procedure involves measurements at 12 precisely known wind speeds, nominally 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8, 1.0, 2.0, 4.0, 8.0, and  $10.0 \text{ m}\cdot\text{s}^{-1}$ . Figure 5 depicts wind speed calibration data for an HSM sensor module at two different ambient temperatures, 21 and  $40^\circ\text{C}$ . The fit of the response model form (Eq.1) is excellent, but the slight difference in response characteristics, as reflected in the values of  $a_0$ ,  $a_1$ , and  $a_2$ , was typical. Work is underway to streamline the wind speed sensor calibration procedure and establish an effective temperature compensation algorithm.

**Figure 5. Typical wind speed sensor responses at 21 and  $40^\circ\text{C}$ .**



## HSM SENSOR PERFORMANCE

### Outdoor Testing

Results of a preliminary evaluation of HSM sensor performance against the full size sensors of a Vaisala/Handar RAWS weather station in a natural outdoor environment revealed several minor inconsistencies.

**Figure 6. Heat Stress Monitor wind speed measurements outdoors.**

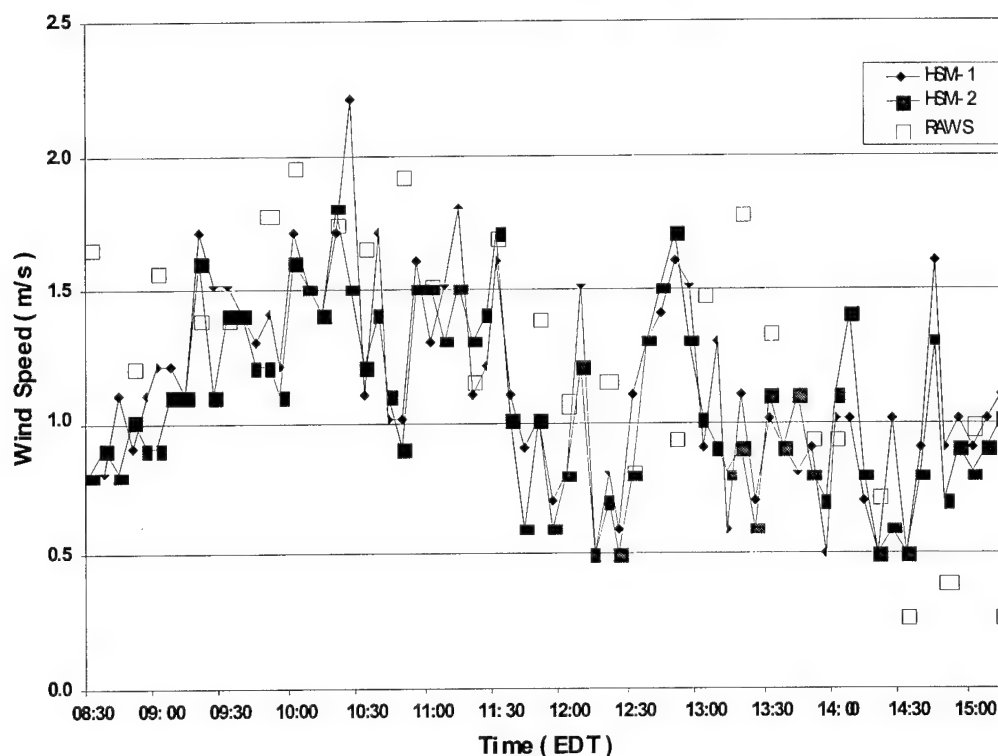


Figure 6 shows wind speed measurements from two prototype heat stress monitors and contemporary 15-minute average wind speed measurements obtained from the weather station's sonic anemometer on 23 June 2000, outside the USARIEM building. Figure 7 shows air temperature measurements for the same time period from the two heat stress monitors and the RAWS weather station. Although agreement between the two HSMs is generally quite good throughout the day, there are occasionally substantial differences between the HSM and weather station values. There are several factors that may be responsible for these observed differences. These include the considerable differences in sensor thermal mass and related response time constants as well as the undesirable direct and indirect effects of solar radiation on the sensors themselves. The HSM air temperature and humidity sensors are quite exposed to wind and radiation effects whereas the weather station air temperature and relative humidity sensors are protected with the traditional "gill" type solar radiation shield. Additionally, it should be noted that each 6-minute interval HSM data point represents the average value over a two minute measurement period. This sampling strategy, driven largely by the HSM battery power budget, means that the remaining four minutes within each 6-minute interval are not sampled. In contrast, the weather station sampled all minutes within its 15-minute averaging/reporting interval. Thus, although the weather station values provide an important benchmark reference, and efforts are underway to improve HSM sensor performance, the trade-off benefits of a pocket-sized device mitigate the need for absolute comparability.

Figure 7. Heat Stress Monitor air temperature measurements outdoors.

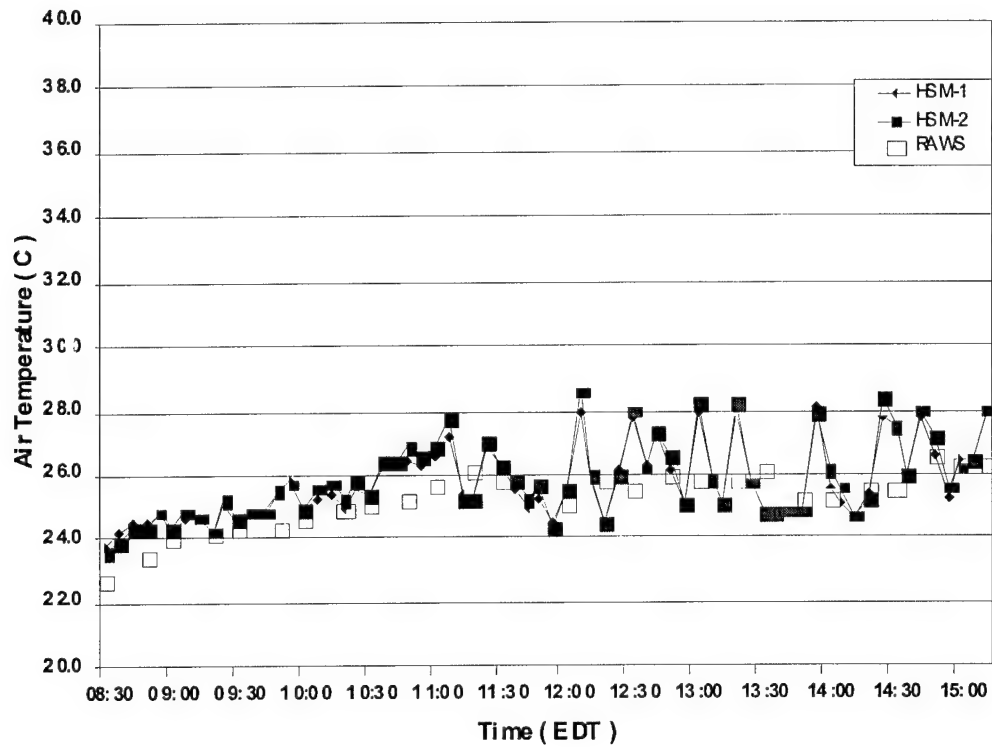


Figure 8. Heat Stress Monitor relative humidity measurements outdoors.

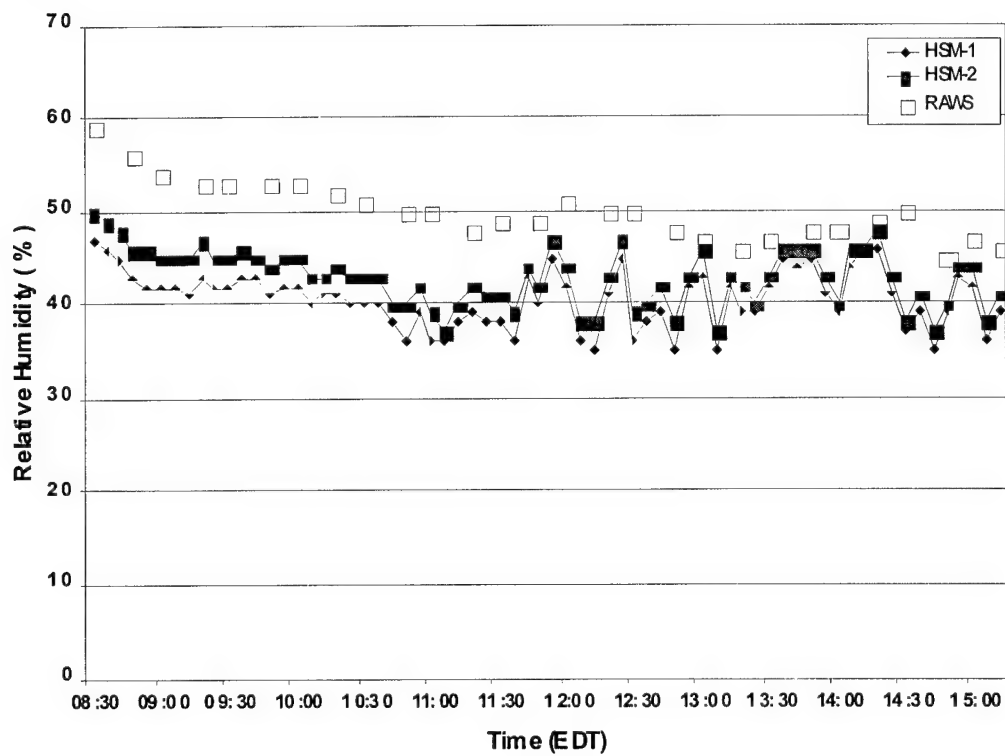
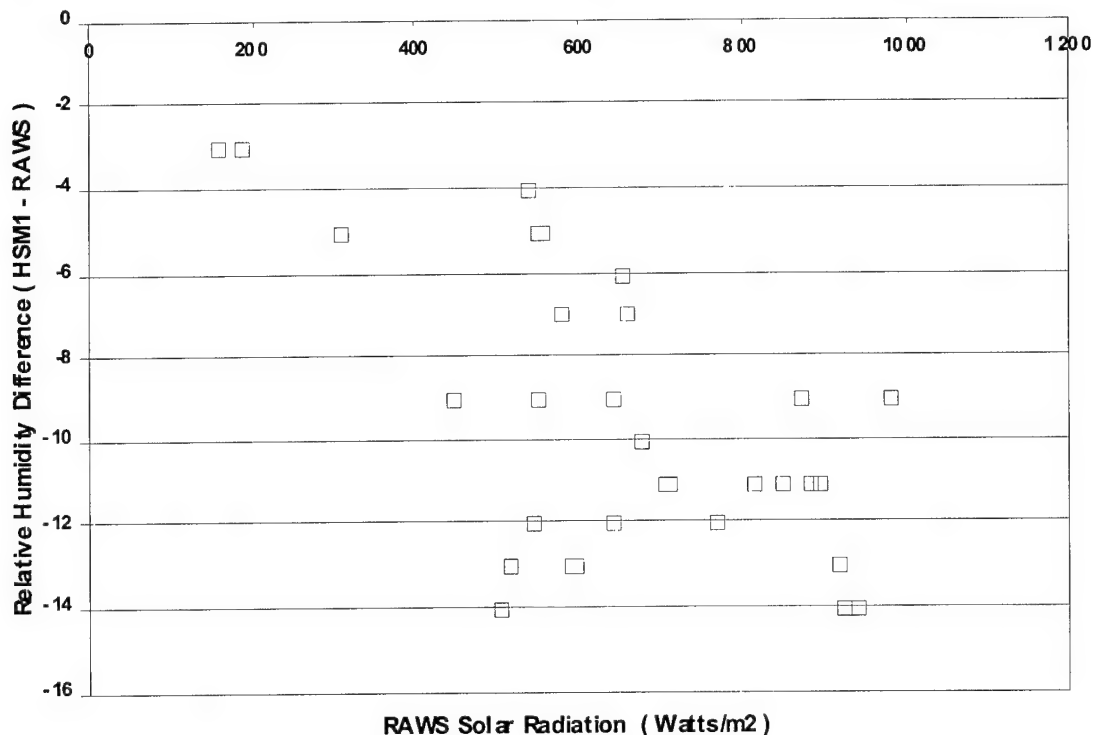


Figure 8 shows the HSM relative humidity sensor data compared with the weather station data. Although the HSM relative humidity sensor readings had been well within the accuracy specification of  $\pm 5\%$  in the chamber calibration environments, HSM readings outdoors were occasionally as much as 14% lower than the weather station readings. The magnitude of those differences appeared to be related to the ambient solar radiation levels. Figure 9 suggests that there is an undesirable interaction between the ambient solar radiation and the HSM's RH sensor reading.

**Figure 9. Solar radiation influence on HSM relative humidity readings.**



The most likely cause of these discrepancies is the spurious solar heating of the air within the HSM's small fritted stainless steel humidity sensor enclosure. It is likely that a corrective algorithm, using data from the HSM's dry bulb, wind speed, and black globe sensors, could be developed and implemented in firmware to correct or at least minimize this effect.

#### **MILITARY USER COMMENTS**

The temporary distribution of four prototype HSMs to Army Ranger units in the summer of 2000 was intended to get preliminary feedback on overall perceptions of suitability for heat stress management applications in training situations. The users were advised of the solar heating effects on the humidity and air temperature sensor readings and were advised to keep the HSM out of the sun until measurements were taken. The prototypes were recovered in the fall of 2000 along with the comments from the Ranger users.

#### **4<sup>th</sup> Ranger Training Battalion**

The medics at 4<sup>th</sup> Ranger Training Battalion, Camp Rogers, Fort Benning, Georgia, reported that they had used the HSM and had in fact relied on it after their existing electronic WBGT monitor failed in late summer. The medics suggested that an additional HSM operational mode that allowed real-time readout of outdoor conditions to a PC located inside the clinic would be a very desirable enhancement.

#### **5<sup>th</sup> Ranger Training Battalion**

A Memorandum for Record from the Operations Officer, 5<sup>th</sup> Ranger Training Battalion, Camp Merrill, Dahlonaga, Georgia, stated that the HSM was used in two command post exercises. Their feeling was that the HSM was convenient to use but provided the same information "...currently derived from the wet bulb and the 5<sup>th</sup> RTBn Ranger Instructor Guide". A concluding paragraph stated: "If we can get them for free they are great, but if we are paying for the item, maintain current operating procedures."

#### **6<sup>th</sup> Ranger Training Battalion**

An email comment from the Executive Officer, 6<sup>th</sup> Ranger Training Battalion, Camp Rudder, Eglin AFB, Florida, stated: "We get new hardware all the time to try out, especially in SOCOM, but the HSM is one of those rare instances where the guys actually find the equipment better and more convenient." The Ranger's at Camp Rudder asked to keep their HSM until it needed to go back for the sensor firmware upgrades.

#### **75<sup>th</sup> Ranger Regiment**

The preventive medicine staff at 75<sup>th</sup> Ranger Regiment, Fort Benning, Georgia, reported some minor differences in the Wet Bulb-Globe Temperature (WBGT) index values measured by the HSM and their existing system in full sun conditions. Following return of the prototype to USARIEM, Regimental Medical Operations Officer asked to be included in any future hot weather evaluations of the HSM.

### **CRDA-RELATED ACTIVITIES**

#### **Cooperative Efforts**

A major goal of this CRDA was to leverage research and development resources by eliminating redundant expenditures for mutual benefit. One item in the CRDA statement of work for both USARIEM and Occ-Consult called for the short term loan of prototype HSMs for testing purposes by either party on an as needed basis. This provision proved unnecessary and no prototype HSMs were loaned or borrowed during the period of this agreement. Other items in the statement of work called for technical assistance and predictive modeling support from USARIEM in return for information on HSM industrial operations experience

and related human studies. There was productive interchange on these issues, but USARIEM's modeling support role diminished as Occ-Consult began to develop its own modeling paradigm for the deep mine application. The most productive element in the statement of work was the considerable coordination of engineering and development contracts that focused on common design elements and component fabrication. Our partner benefited from the general system definition and functional enhancements arising from the Rome Labs/Synectics and SwRI contracts. The Army benefited from our partner's contract effort with SwRI for the production of 30 prototypes. That effort established an efficient assembly process and our access to the rapid-prototype urethane case molds and calibration procedures led to cost savings to the Army when USARIEM purchased 10 prototypes of its own. The final coordinated contract effort was an engineering development and support contract to SwRI, with funds provided by USAMMDA. Deliverables to USARIEM included complete engineering design package for production-level hard tooling for the HSM keypad and case components. Occ-Consult paid Anchor Plastics Ltd., Sydney, Australia for actual fabrication of the hard tooled injection molds that could be used to produce the HSM components at minimal cost. The spirit and intent of this cooperative effort was that, should the Army decide to field the HSM, production-level case components could be acquired at cost from Occ-Consult. USARIEM has purchased five production level HSM's that utilize the new case components from Totally Texas Technologies, Inc., San Antonio, Texas.

#### **Meeting at USAMMDA**

On 28 January, 2000, a meeting was held at U.S. Army Medical Materiel Development Activity (USAMMDA), U. S. Army Medical Research and Materiel Command (USAMRMC), Fort Detrick, Frederick, Maryland. The purpose of that meeting was to lay out status of HSM Intellectual property rights and technology transfer issues affecting final production and commercialization of HSM. Attendees included Director, USAMMDA (Dr. Nelson), MPMC Research Area Director, RAD III ( LTC Friedl), MPMC Legal Office (Ms. Arwine), Southwest Research Institute engineering and legal staff representatives ( Mr. Kevin Honeyager and Mr. Rodriguez), CRDA Principle Investigator Occ-Consult (Dr. Bates) and CRDA Principle Investigator USARIEM (Mr. Matthew). There was general agreement that the sooner a production level HSM could be put into production for a mass market, the sooner a low cost, reliable HSM could be made available for any potential military users. It was noted by Ms. Arwine that Occ-Consult would be required to formally request licensing rights and negotiate fees for any Army-held intellectual property rights to HSM, before proceeding with full scale production. These issues were outlined in some detail to Dr. Bates in a meeting that same day with MPMC Office of Research Technology Applications (ORTA) ( Dr. Mele)

### **HSM Patent Activities**

Documents relating to the HSM submitted by USARIEM and through Medical Research and Materiel Command, Staff Judge Advocate Office, Fort Detrick, Frederick, Maryland were:

Matthew, W.T, L.A.Stroschein, and J. M. McGrath. "Environmental Heat Stress Monitor". Invention Disclosure submission to MRMC Legal Office, September 1999.

Matthew, W.T, L.A.Stroschein, and J. M. McGrath. "Environmental Heat Stress Monitor", Provisional Patent Application filed February 2000.

Matthew, W.T, L.A. Stroschein, and J. M. McGrath. "Environmental Heat Stress Monitor", U.S. Patent application Serial Number 09/780,571, filed February 2001. Note: Occ-Consult, Ltd./Dr. Bates was asked but declined to participate as co-inventor.

Southwest Research Institute, exercising its rights under provisions of the Federal Acquisition Regulations (FAR), filed for and was awarded the following patent:

Honeyager, K., T. McDaniel, and L. Canady. "Hand-Held Environmental Monitor", U.S. Patent No.6,111,501, issued 29 August 2001.

## **DISCUSSION**

### **HSM TECHNICAL MATURITY**

As an Army technology base product, the HSM has achieved a very high level of technical maturity. The user interfaces are logical and straightforward. The on board calibration and system diagnostic resources as well as the PC-based communications and display software systems are solid. The only development issue as yet unresolved is a practical, rational firmware solution to mitigate the apparent effects of high ambient solar radiation on air temperature and humidity measurement accuracy. Work is underway to characterize the relevant interactions and develop the necessary algorithms. The firmware correction would need to be implemented before any extensive field testing of the HSM is initiated.

### **HSM APPLICATIONS**

The range of applications for the HSM is substantial. Significantly, the HSM has found no strong proponent within the Army to support final development and fielding. In an era of Army transformation, there appears to be a cultural reluctance to move beyond the somewhat limited 50-year old WBGT index and look-up table approach. It is worth noting that although the Army's current preventive medicine doctrine for heat stress management uses WBGT

index (2), the WBGT is not a standard meteorological measurement nor is it readily available from deployed Army or DoD weather assets. It is also worth noting that the specific doctrinal guidelines on safe work time, optimal work rest cycle limits, and hourly drinking water requirements assigned to each WBGT category, were in fact determined by using the USARIEM model and making necessary assumptions to translate the non-rational WBGT values into standard weather parameters suitable for model input. The HSM could be used to help reduce the risk of heat injury in military or industrial settings as well as in sports/physical training applications. The HSM can be used outdoors, in crew compartments and other enclosed work space environments in real-time. With its automated data logging capability, it can also be used to provide operational test documentation or survey data for heat stress conditions over a 24-hour period. HSM measurements of the ambient environment could be used in a variety of human factors engineering/development projects and the programmable microprocessor provides an integrated platform that is easily adaptable for use with a wide range of user-specific models and algorithms. As a result of our CRDA with Occ-Consult, the HSM has been adopted for use as the primary heat stress management device in a large commercial deep mine operation in Australia.

#### **TECHNOLOGY TRANSFER**

Final resolution of intellectual property (IP) rights issues for HSM is a major stumbling block to full scale production and commercialization of this device. On 11 May 2001, the USARIEM inventors assigned all rights in U.S. Patent Application, serial number 09/780,571, "Environmental Heat Stress Monitor" to the Army. As of this writing, we have no word on the status of that patent filing. Without formal recognition of Army intellectual property rights to at least some aspects of HSM, the ability of our technology transfer office to negotiate licensing agreements with our CRDA partner, or any other potential manufacturer, is limited. Although the Army has royalty free rights to produce HSMs under the patent obtained by SwRI, the revenue streams that might otherwise accrue to the Army through a licensing agreement with a commercial enterprise are lost. The current uncertainty in Army IP rights in HSM is likely to discourage interested manufacturers from getting involved, so a clear and timely resolution of that issue is the crucial first step in transferring this technology. It is reasonable to expect that economies of scale arising from a full commercialization would reduce unit costs, currently \$3,600, and this is absolutely critical to acceptance of HSM as a NDI solution for military users. A unit cost of \$1500 to \$2,000, competitive with existing electronic WBGT meters, should be possible.

## **CONCLUSIONS**

### **HSM TECHNOLOGY STATUS**

We conclude that the HSM is a mature Army technology base product. Current features and capabilities substantially expand the range of potential applications for both military and industrial users. In an era of increased terrorist threats, the HSM could provide local, real-time heat injury risk assessment and heat stress management guidance to protectively encapsulated military or civilian first responders in chemical or biological attack scenarios.

#### **Sensors**

A modest analytical effort is needed to finalize a rational corrective algorithm, implementable in firmware, that would mitigate the effects of high ambient solar radiation on HSM air temperature and humidity measurement accuracy.

#### **Wind Speed Calibration**

A modest analytical effort is needed to streamline HSM wind speed sensor calibration procedures. Simplifying calibration routines will reduce costs for initial production and improve maintainability in any re-calibration schedule adopted for the HSM.

#### **Army Users**

It appears that Army users are interested in HSM technology at the operational level. However, the current Army preventive medicine doctrine fixation with the 50- year old WBGT index will, even more than HSM unit cost, determine what if any role the HSM plays in the transformed Army of the 21<sup>st</sup> century.

#### **Technology Transfer/Dual Use**

A final determination of Army IP rights in HSM, one way or the other, is crucial to a viable commercialization track for this product.

## **RECOMMENDATIONS**

- Finalize and implement sensor correction processes in HSM firmware.
- Complete outdoor testing of HSM in hot-wet and hot-dry field environments.
- Implement HSM firmware enhancements that use on-board barometric pressure sensor data to more accurately model heat stress at high terrestrial altitude.
- Hand off HSM technology.

## REFERENCES

1. AFRL (no authors listed), *Development of a Miniaturized Heat Stress Monitor Prototype*, Final Technical Report, U.S. Air Force Research Laboratory, Rome, N.Y., AFRL-IF-RS-TR-1998-83, May 98.
2. FM 21-10, MCRP4-11.1D Field Hygiene and Sanitation. Headquarters, Department of the Army and Commandant of Marine Corps, Washington, DC, 21 June 2000.
3. Gonzalez, R.R., T.M. McClellan, W.R. Withy, S.K. Chang, and K.B. Pandolf. Heat Strain Models Applicable for protective clothing systems: comparison of core temperature response. *J.Appl. Physiol.* 83 (3) 1017-1032, 1997.
4. Matthew, W.T., J.A. Gonzalez, R.R. Gonzalez, G. Bates and C. Gazey. *Field Testing of a Prototype Heat Stress Monitor: System Performance and Applicability to Commercial Mining in Australia*. USARIEM Technical Report T99-7, June 1999.
5. Pandolf, K.B., L.A. Stroschein, L.L. Drolet, R.R. Gonzalez, and M.N. Sawka. Prediction Modeling of Human Responses in the Heat. *Comput. Biol. Med.* 6:319-329, 1986.